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# Coastal Overwash: Part 2, Upgrade to SBEACH

*by Magnus Larson, Randall A. Wise, and Nicholas C. Kraus*

PURPOSE. This Coastal and Hydraulics Engineering Technical Note (CHETN) provides information about an improved capability to mathematically model overwash caused by elevated water elevation and wave runup. An upgrade to SBEACH (Storm-induced BEAch CHange Model, a numerical model for simulating storm-induced beach profile change) is described to simulate sediment transport and subaerial profile response by overwash associated with wave runup. The enhanced SBEACH model is validated with field data on overwash of protective dunes at Ocean City, MD, and overwash of the low and wide northern end of Assateague Island, MD. The new algorithm replaces that of Kraus and Wise (1993) previously employed in SBEACH.

BACKGROUND. This CHETN is the second in a series and follows Part 1 (Donnelly et al. 2004), which reviews the physical processes of overwash and washover. Terminology and significance of these processes for coastal engineering and science are presented there. Overwash is the flow of water and sediment over the crest of the beach that does not directly return to the water body (ocean, sea, bay, or lake; hereafter collectively referred to as "ocean") where it originated. Washover is the sediment deposited by overwash. In the United States, overwash is most common on the barrier islands of the Atlantic Ocean and Gulf of Mexico coasts, but it also occurs around the Great Lakes, on low-profile coasts of the mainland, on spits, and on gravel or shingle beaches. The occurrence of overwash is expected to increase because of rise in sea level and diminished sediment supply along many coasts. Calculation capability is required to assess vulnerability to overwash and breaching, to develop shore-protection measures such as sand dunes, and to formulate sediment budgets.

Overwash begins when the runup level of waves, usually coinciding with a storm surge, exceeds the local beach or dune crest elevation. As the water level in the ocean rises to inundate the beach or dune crest, a steady sheet of water (called sheetwash) and sediment overwashes the barrier. Overwash by wave runup ends after the storm surge elevation subsides, leaving washover deposits, typically as easily observed sheets of sand (Figure 1). Overwash by complete inundation of the beach and dune is a distinct process to overwash by runup and is not treated here.

This technical note introduces a model for computing sediment transport over a beach or dune crest due to wave runup. In such a situation, the mean water level is located below the crest of the beach or dune, and transport of water and sediment occurs through runup waves overtopping the crest. The sediment may be transported landward of the foreshore or the beach or dune crest, where it is deposited because the transporting capacity of the overtopping waves is reduced with distance from the crest. A computational algorithm is developed based on the model and implemented in the profile response model SBEACH to simulate several recorded field cases of overwash. Technical aspects and tests of SBEACH model are documented in Larson and Kraus

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Figure 1. Overwash along northern end of Assateague Island, MD, immediately after the 6-7 February 1998 storm.

(1989, 1998), Larson et al. (1990), and Wise et al. (1996). The capability of the enhanced SBEACH is then demonstrated by comparison to field data. The equations are presented to familiarize engineers with the underlying physical processes to assess the applicability of the model to their studies and projects.

First, equations are presented to calculate the net sediment transport rate in the distinct regions of the subaerial profile: (1) the swash zone, (2) the beach and dune crest, and (3) the region landward of the crest. The transport relationships employed are based on local water velocity, required for each region. Connection of the transport in the swash zone and beach or dune region with that in surf zone is accomplished by a matching approach similar to that introduced by Kraus and Wise (1993) for the original SBEACH model. The enhanced SBEACH model is validated through comparison to data from the east coast of the United States. These data encompass high-quality records of overwash during storms including pre- and post-storm beach profile surveys, as well as detailed time series of waves and water level. Two physical situations are modeled: (1) overwash of a high dune, and (2) overwash of a low and wide barrier island. This technical note also contains the result of several hypothetical simulations to demonstrate the capabilities of the model in simulating profile response if overwash occurs.

OVERWASH ALGORITHM. The overwash algorithm in the previous version of SBEACH was developed by Kraus and Wise (1993) and Wise et al. (1996) to simulate dune erosion produced by a major storm that struck Ocean City, MD, in January 1992. During the storm, the dunes experienced marked shoreward sediment transport, and re-evaluation of the shore-protection design was warranted. Kraus and Wise (1993) developed an overwash algorithm based on physical arguments together with geometric constraints formulated from observations. Measured profile evolution in the dune region during the storm was well reproduced by the algorithm. Because some of the assumptions made in the calculation procedure were intuitively based, further work (Larson et al. 2004b) was considered necessary to solidify the physical foundation of the overwash model and is summarized here. Although new transport relationships are introduced, several concepts in the Kraus and Wise (1993) model are retained.

To establish the overwash and washover algorithms, the subaerial profile is schematized into three regions as: (1) the swash zone, (2) the beach and dune crest, and (3) the area landward of the crest (Figure 2), for which different sediment transport relationships are developed. Each transport relationship is formulated in terms of the local velocity obtained with a simple model of the wave runup hydrodynamics. The crest region is considered to be of limited spatial extent (compared to the other regions), and the transport calculated at the crest acts as a boundary condition connecting the transport regions on each side of the crest. The matching between the transport at the crest and the transport in the swash is carried out in the same way as previously done in SBEACH.

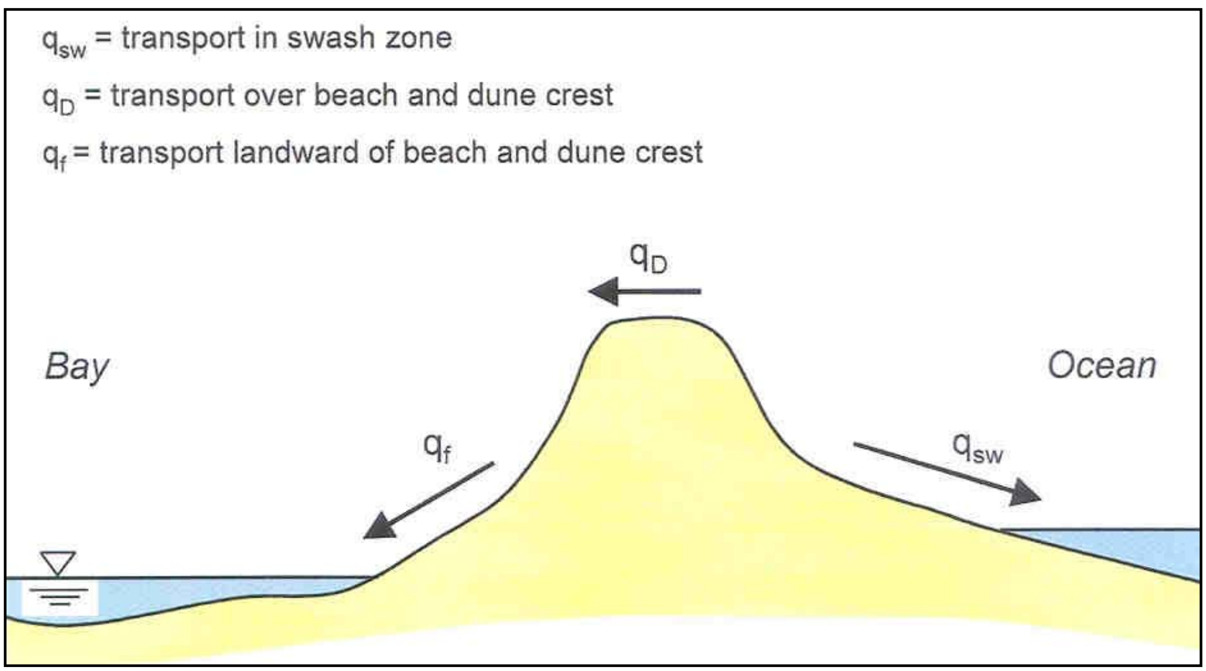


Figure 2. Three regions of sediment transport described in overwash algorithm (arrows indicate typical net transport direction during overwash).

**Swash Zone Sediment Transport.** Larson et al. (2001, 2004a) developed a formula describing the net sediment transport $q_{sw}$ over many cycles in the swash zone,

$$q_{sw} = K_c\left(\frac{u_b^3}{g}\right)(\tan ß_l - \tan ß_e)\ (t_0/T) \tag{1}$$

where $K_c$ is an empirical transport coefficient, $u_b$ the front speed of the uprushing wave (bore), $g$ the acceleration of gravity, $\beta_l$ the local foreshores slope, $\beta_e$ the equilibrium foreshore slope, $t_o$ the time during which a specific location is submerged, and $T$ the swash period (here taken to be equal to the incident wave period as a representative value). Two main differences distinguish this formula from that previously employed in SBEACH for the swash zone:

1. The transport is expressed with respect to the deviation from an equilibrium foreshore slope, which ensures robust development towards a realistic foreshore shape. The equilibrium slope is a model input.
2. The time during which there is water and sediment movement at a particular location is explicitly taken into account.

Based on simple ballistics theory, the speed of the uprushing wave front is estimated as (compare Shen and Meyer 1963, Waddell 1973, Hughes 1992):

$$u_b^2 = u_{bs}^2 - 2gz \tag{2}$$

where the index $s$ denotes the boundary between the swash zone and the surf zone, which is the location at which the wave uprush starts (taken to be approximately the still-water shoreline), and $z$ is the distance from the still-water level to the location where $u_b$ is calculated. From the simple theory, the time of submergence is given by:

$$\frac{t_0}{T} = \sqrt{1 - \frac{z}{R}} \tag{3}$$

in which $R$ is the runup height assumed to correspond to the situation when $u_b = 0$ in Equation 2 yielding $R = u_{bs}^2/2g$. In a predictive mode, $R$ is determined from an appropriate runup height formula. Substituting Equations 2 and 3 into Equation 1, and substituting the assumed equation of how $R$ depends on $u_{bs}$, produce the following transport formula for the swash zone:

$$q_{sw} = K_c 2\sqrt{2g}\, R^{3/2}\left(1 - \frac{z}{R}\right)^2 (\tan ß_l - \tan ß_e) \tag{4}$$

Thus, the transport at $x = x_s$ ($q_{sw,s}$), that is, at the boundary between the swash and the surf zone where $z = 0$, is given by:

$$q_{sw,s} = K_c 2\sqrt{2g}\, R^{3/2} (\tan ß_l - \tan ß_e) \tag{5}$$

Normalizing the transport at $x$ (Equation 4) with the transport at $x_s$ (Equation 5) yields:

$$\frac{q_{sw}}{q_{sw,s}} = \left(1 - \frac{z}{R}\right)^2 \frac{\tan ß_l - \tan ß_e}{\tan ß_{ls} - \tan ß_e} \tag{6}$$

Finally, assuming a constant, representative foreshore slope βfs results in:

$$\frac{q_{sw}}{q_{sw,s}} = \left(\frac{x - x_r}{x_s - x_r}\right)^2 \tag{7}$$

where $\tan\beta_{fs} = \tan\beta_l = \tan\beta_{ls}$, implying $z = \tan\beta_{fs}\,(x_s\text{-}x)$, and the subscript $r$ denotes the runup limit. Equation 7 differs from the previously used equation in that the power is 2 instead of 3/2. This difference arises from explicitly taking into account the duration of the overwash during a wave cycle (see Equation 3). A formulation such as Equation 7 for the swash zone transport requires $q_{sw,s}$ as an input, obtained from calculation of the transport rate in the surf zone. Thus, the amount of material supplied to, or taken way from, the swash zone is determined by the conditions in the surf zone, whereas the shape of the transport rate is given by Equation 1.

If overwash occurs, the shoreward limit of the runup would be at a hypothetical location obtained by extrapolating the profile beyond the crest using the slope employed in the runup calculations.

Hydrodynamic quantities associated with the bore front would also be calculated from a runup height based on such a hypothetical profile. Schüttrumpf (2003) showed that such an approach is satisfactory through comparison with laboratory data. In combining the swash zone transport formula with the transport rate at the beach or dune crest, some matching is necessary. The matching approach must yield the correct transport rates at the crest and at the shoreward boundary of the surf zone simultaneously as the functional dependence for the net transport in the swash zone, as described by Equation 7, is maintained.

**Sediment Transport Over Beach/Dune Crest.** In the overwash model, it is necessary to determine the transport rate *qD* over the beach/dune crest (see Figure 2). It is assumed that the sediment transport rate in the overwash is proportional to the average rate of water flow crossing the top of the dune during a swash cycle. This is in agreement with the findings of Hancock and Kobayashi (1994) and Kobayashi et al. (1996). Based on laboratory experiments, they found a linear relationship between the sediment transport and the flow in the overwash, implying an approximate constant average sediment concentration in the overwash flow. An alternative approach would be to assume a transport rate proportional to a certain power of the representative velocity at the crest. In fact, if a power of 3 is employed in such a transport relationship, essentially the same transport formula is obtained as assuming a transport rate related to the average flow rate, as will be shown after the following derivation.

Figure 3 shows a typical dune exposed to overtopping, where a certain volume of water is overwashed during each wave cycle. For simplicity, the wave and water level conditions are kept constant in the following derivation. In generalizing the model, the temporal variation in these quantities is described by employing representative values at each time-step, but allowing them to change with time. The height of the dune crest above the Stillwater level is denoted $z_D$ (includes the effect of possible surge), the runup height $R$, the velocity of the bore front passing the dune crest $u_D$, and the height of the uprushing bore at the dune crest $h_D$.

Employing Equation 2, the speed of the bore front is calculated as:

$$u_D = \sqrt{u_{bs}^2 - 2gz_D} \tag{8}$$

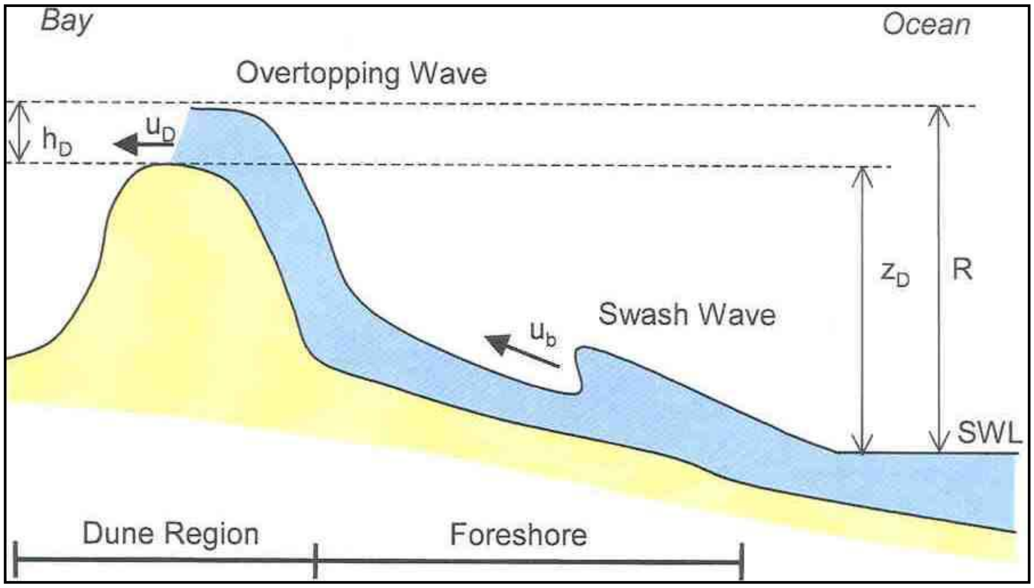


Figure 3. Definition sketch showing a dune crest being overtopped by wave runup.

Introducing the runup height gives:

$$u_D = \sqrt{2g(R - z_D)} \tag{9}$$

The relationship between the bore speed and bore height at the front may be described by (Cross 1967, Miller 1968):

$$u_D = \alpha\sqrt{gh_D} \tag{10}$$

where α is an empirical coefficient with value of order unity.

The typical flow rate $\dot{V}_D$ in the overwash is estimated from:

$$\dot{V}_D \sim u_D h_D = \frac{2\sqrt{2g}}{\alpha^2}(\mathrm{R} - z_D)^{3/2} \tag{11}$$

where Equations 9 and 10 were used. To determine the overwash volume, the duration during which water flows over the dune crest must be known. For the case of a bore moving up and down a plane foreshore, the time $t_0$ that a certain location is submerged may be calculated from Equation 3. It is assumed that the duration of the overwash during a swash cycle is proportional to $t_0$ calculated from $z = z_D$. Thus, the overwash volume $V_D$ is estimated from:

$$V_D \sim \dot{V}_D t_0 \sim \frac{2\sqrt{2g}}{\alpha^2} T \frac{(R-z_D)^2}{\sqrt{R}} \tag{12}$$

The average overwash flow during a swash event is given by $V_D/T$. As discussed in the preceding, the transport of sediment in the overwash is expressed in terms of the flow, yielding a transport relationship according to:

$$q_d = \frac{K_D}{\alpha^2} 2\sqrt{\frac{2g}{R}}\ (R - z_D)^2 \tag{13}$$

where $K_D$ is an empirical transport coefficient. The two empirical coefficients appearing in Equation 13 may be absorbed into one coefficient $K_{Da} = K_D/\alpha^2$ for calculations. If a transport relationship is assumed where the rate is proportional to $u_D{}^3$, the resulting expression will be identical to Equation 13. In such a case the transport relationship governing overwash may be written:

$$q'_D = K_c \frac{u_D^3}{g} = K_c 2\sqrt{2g}\,(R - z_D)^{3/2} \tag{14}$$

where $q'_D$ is the transport during the portion of the swash period when overwash takes place and $K_C$ is a nondimensional coefficient ($g$ was introduced in the denominator to obtain the proper dimensions). The duration of the overwash is estimated as before (Equation 3), leading to the following expression for the average transport over the dune during an overwashing wave:

$$q_D = K_B 2\sqrt{\frac{2g}{R}}\,(R - z_D)^2 \tag{15}$$

where $K_B$ is another nondimensional coefficient. Thus, Equations 13 and 15 are identical apart from the form of the coefficient. The updated model employs Equation 15 to compute transport at the dune crest, using a value of $K_B = 0.005$.

In the previous version of SBEACH, $q_D$ was calculated based on a transport relationship where the rate was proportional to the velocity cubed similar to Equation 14. The flow depth at the crest was estimated through linear interpolation from the water level at the landward boundary of the surf zone to the crest location (compare Schüttrumpf 2003). Equation 10 was employed to compute the flow velocity at the crest based on α = 2. As previously discussed, no attempt was made to include an estimate of the duration of the overwash flow during an event, leading to a different power in the net transport rate distribution.

**Sediment Transport Landward of Beach/Dune Crest.** In the previous version of SBEACH, a linear decay shoreward from $x = x_D$ to $x = x_{r*}$ was employed to estimate the sediment transport landward of the crest, where $x_{r*}$ is derived through the "equivalent volume approach" (Wise et al. 1996). In the updated model, a simple method is applied to estimate the velocity and its spatial variation on the shoreward side of the crest, and these velocities are used to compute the sediment transport rates based on a formula similar to Equation 14.

After the water is transported over the beach or dune crest, it flows downhill depending on the hydrodynamic, topographic, and sedimentologic conditions. Initially, especially on the landward side of a steep beach or dune crest, the flow accelerates. However, after a fairly short distance, the flow enters a part of the profile where the beach slope is typically milder with gradual changes in elevation, and a balance between gravitational and frictional forces is obtained. In this region, the change in velocity of the flowing water is mainly due to lateral spreading and (possibly) infiltration. Assuming a saturated beach, which implies that velocity change is mainly due to lateral spreading, continuity of flow locally at the bore front may be expressed as:

$$Q = Bvh \tag{16}$$

where $B$ is the width of the flow, and $v$ the velocity at the bore front shoreward of the crest. Assuming a relationship between velocity and depth in accordance with Equation 10, the following relationship is obtained:

$$Bv^3 = B_D v_D^3 \tag{17}$$

where the subscript $D$ denotes conditions at the dune crest, as before, and $v_D = u_D$. To proceed, an assumption is needed on how the flow spreads laterally, and the simplest approach is to choose a linear description according to:

$$B = B_D + \mu s \tag{18}$$

where $\mu$ is an empirical coefficient and $s$ is a coordinate originating at $x = x_D$, increasing shoreward (see Figure 4). A linear spread is supported by the shape of the washover fans typically observed in the field (Donnelly et al. 2004). Substituting Equation 18 into Equation 17 yields:

$$v = \frac{v_0}{(1 + \mu s / B_D)^{1/3}} \tag{19}$$

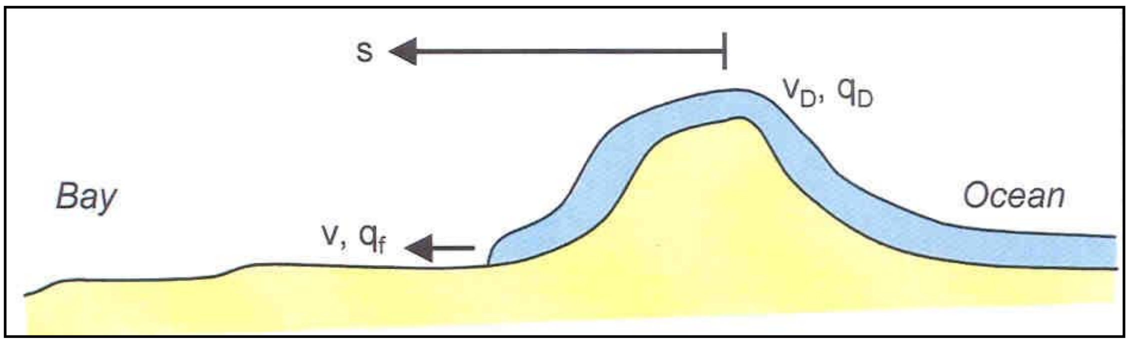


Figure 4. Definition sketch showing overwash spreading landward of a beach/dune crest.

Holland et al. (1991) presented measurements of $v$ for which they proposed a linearly decreasing function with the distance $s$ as a suitable fit. However, Equation 19 equally fits the limited data given in that paper. The power in the denominator (1/3) determines the rate at which the velocity, and, thus, the transport rate, decreases with distance from the crest, which in turn influences the extent of the deposition area. Assuming a transport rate in the flow on landward side of the crest that is proportional to the velocity cubed and normalizing with $q_D$ gives:

$$q_f = \frac{q_D}{1 + \mu s / B_D} \qquad x < x_d \tag{20}$$

**Sediment Transport Distribution.** To derive the transport rate distribution across the entire profile, some additional considerations are required when implementing the transport formulas for the different regions already discussed. On the seaward side of the crest, the swash zone sediment transport (Equation 7) has to be "matched" to the transport at the crest (Equation 15). The previous approach in SBEACH is used, and transport from the shoreward end of the surf zone to the crest is calculated from:

$$q = q_d + (q_s - q_d)\left(\frac{x - x_D}{x_s - x_s}\right)^2 \qquad x_D < x < x_s \tag{21}$$

From the crest and landward ($x < x_D$), Equation 20 is employed using a value of $\mu/B_D = 0.12$, which is maintained as a default value in all subsequent calculations. This value was based on calibration against measured profile change on the landward side of the crest. The width of the overwash flow at the crest ($B_D$) introduces the longshore dimension into the calculations, and $B_D$ is primarily a function of the runup properties and the local topography. At present, there is little background information on $B_D$ or $\mu$ (which represents the spreading angle of the flow), so these two parameters were lumped together in the modeling, even though it would be desirable from a physical point of view to treat them separately.

VALIDATION OF OVERWASH ALGORITHM. The updated model is validated with two storm erosion data sets representing different beach profile configurations. The November 1990 to January 1991 storms at Ocean City, MD, generated overwash of relatively high narrow dunes, whereas the January to February 1998 storms at Assateague Island, MD, produced overwash of a wide low barrier island. Both data sets include pre- and poststorm beach profiles and time-histories of wave height, period, and water level measured from a nearshore gauge. The Ocean City (OC) data set was central in formulating the previous overwash algorithm and is re-examined here to confirm that model capabilities are retained by the new algorithm. The Assateague Island (AI) data set provides a basis for evaluating new model capabilities in simulating overwash of a low barrier island. Additional hypothetical cases are simulated to examine model response to different barrier island conditions including potential for breaching. Elevations are referenced to North Atlantic Vertical Datum of 1988 (NAVD).

Model Calibration. Model calibration was initiated using values employed in previous SBEACH applications at Ocean City (see Wise et al. 1996). Best agreement was achieved with the following parameters (see SBEACH technical report series for details): sediment transport coefficient, $K = 2.5 \times 10^{-6}$ $m^4/N$; slope term, *eps* = 0.005; depth of foreshore, *dfs* = 0.5 m; decay coefficient, *lamm* = 0.3; and avalanching angle = 30 deg. These parameters are identical to the previous calibration except for the notable change in $K$ from $1.5 \times 10^{-6}$ to $2.5 \times 10^{-6}$ $m^4/N$. The change in $K$ is primarily due to the difference in overwash calculation and how $K$ influences overwash. In the previous algorithm, $K$ entered directly in the overwash calculation as a multiplier of the maximum rate of transport at the dune crest. The overwash computation was essentially calibrated for the default value of $K$ to avoid the need for a separate calibration parameter. Because of this, in some cases, higher values of $K$ tended to cause instability and excessive piling of sand landward of the dune.

In the present algorithm, the maximum rate of overwash transport is calculated independently of $K$, using a more physically based approach. The $K$ value still influences the overall magnitude of overwash because it controls the amount of seaward erosion and recession of the foreshore slope, which in turn controls when and to what extent overwash occurs, but the rate of overwash transport is no longer directly a function of $K$.

Experience with the previous SBEACH model indicates that, apart from overwash, the model is not greatly sensitive to values of $K$, which is beneficial in terms of model robustness and stability. If overwash does occur, it is in general the most dynamic erosion process in the model and typically controls values of calibration parameters. The larger value of $K$ in the present validation provides the best agreement in terms of foreshore erosion and washover volumes for the OC and AI data.

**Overwash of Dunes at Ocean City, MD.** Dune erosion and overwash is modeled for the combined 11 November1991 and 4 January 1992 storms (Wise et al. 1996). Figure 5 shows a chart that plots significant wave height H, peak spectral period T, and water level WL for these storms. The values plotted correspond to erosional conditions only, neglecting times of accretion or no wave activity. The less-severe November storm, which had a peak water level of 1.2 m and peak wave height of 3 m, eroded the foreshore; whereas the major 4 January storm, which had a peak water level of 1.2 m and peak wave height exceeding 4 m, produced significant dune erosion and overwash. Pre- and post-storm beach profiles surveyed on 2 November 1991 and 11 January 1992 closely bracket the storms.

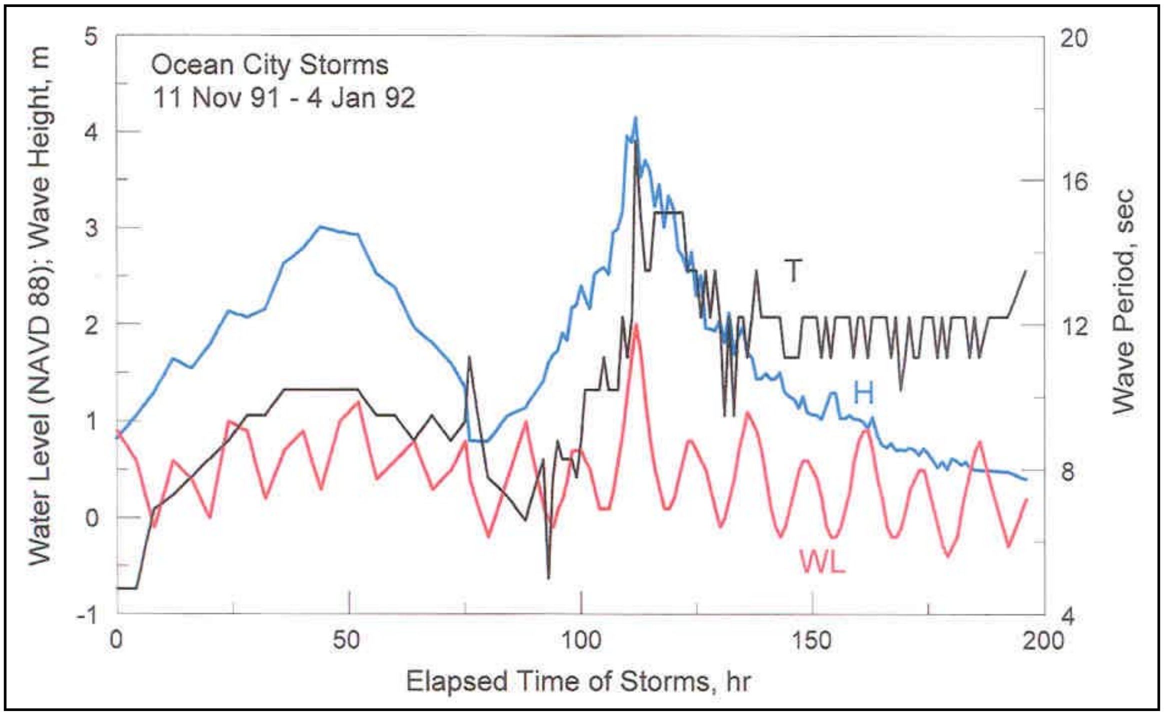


Figure 5. Wave height H, wave period T, and water level WL, for erosional storms occurring from 11 November 1991 to 4 January 1992 at Ocean City, MD.

Figures 6–8 show measured profile response and simulation results at three adjacent monitoring lines located at 45th, 56th, and 63rd Streets. Each pre-storm profile has a slightly different dune crest elevation. More pronounced differences exist in dune width, front slope, and backing elevations – all of which influence the extent of wave overwash and volume of washover deposition.

At 45th and 63rd Streets (Figures 6 and 7, respectively), the model accurately simulates lowering and overwash of the dunes. The landward extent, elevation, and shape of washover deposition is well reproduced. Horizontal recession of the upper beach slope is somewhat under-predicted, but overall the simulation is in good agreement with the measurements. The pre-storm dune widths are similar at 45th and 63rd Streets (~20 m at the base), and observed overwash extends landward of the pre-storm dune face about 40 m at 45th Street and about 70 m at 63rd Street.

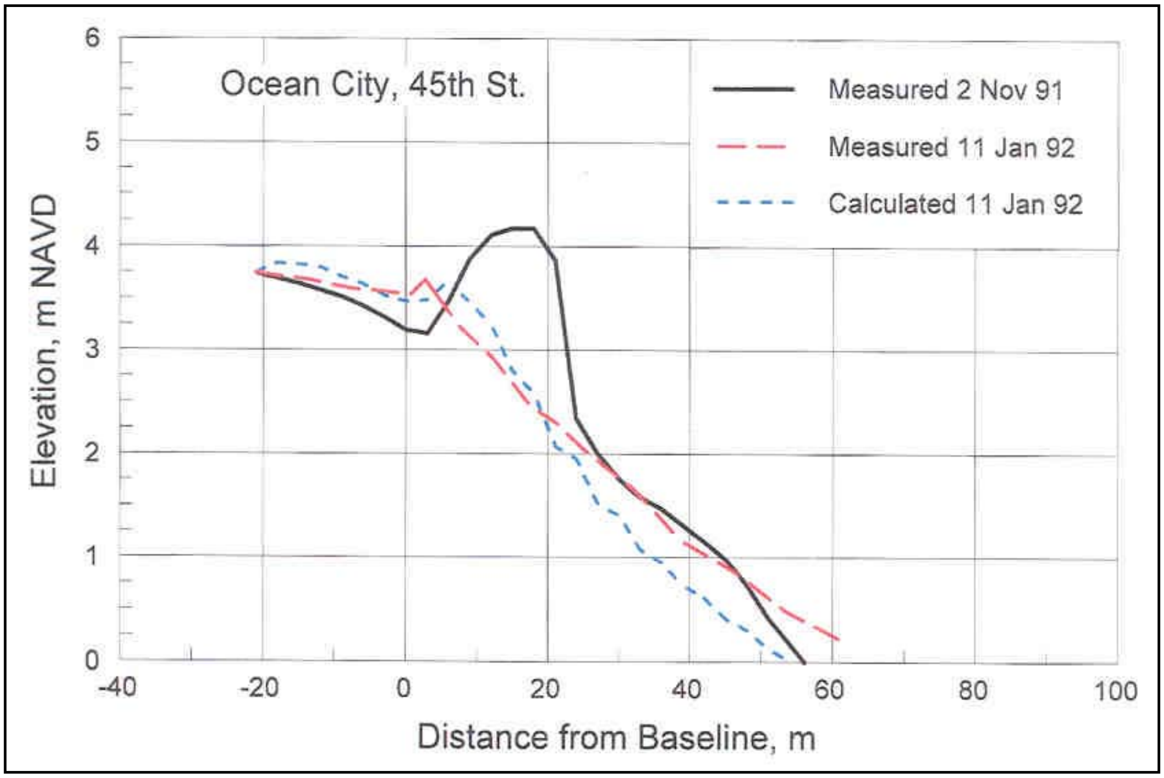


Figure 6. Calculation of dune erosion and overwash, 45th Street (note: ocean is to right and bay is to left in this and all subsequent profile figurers).

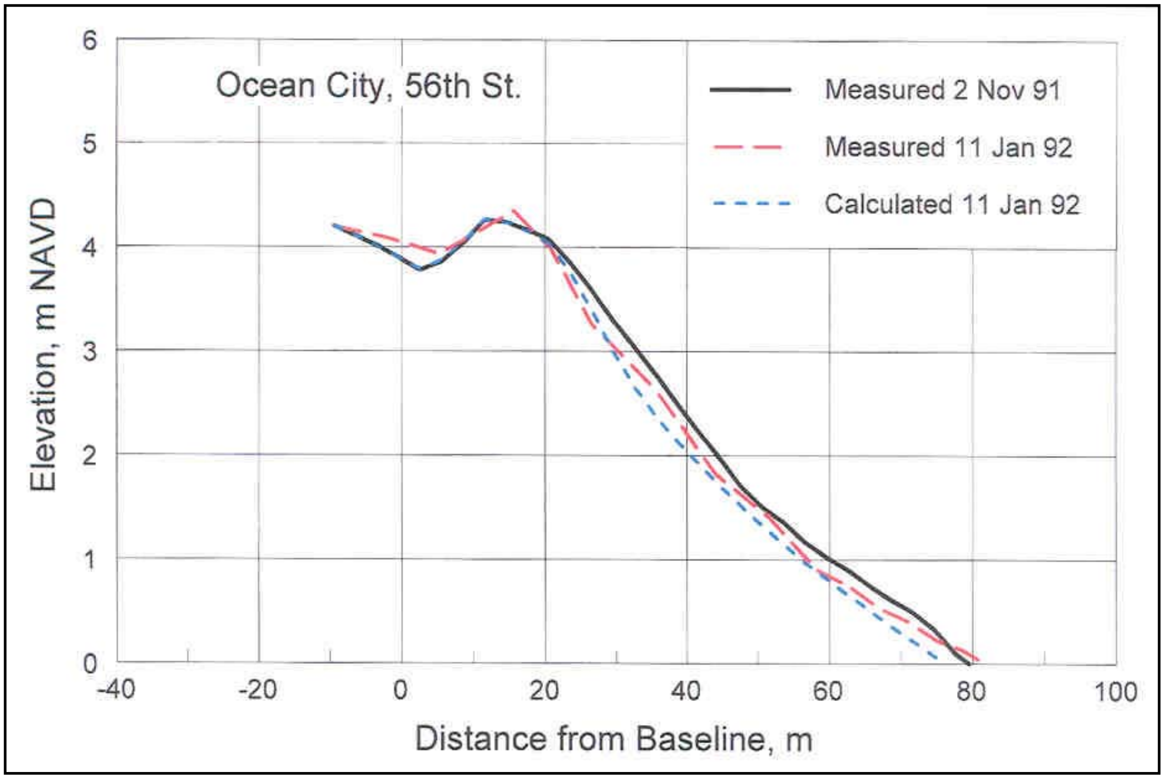


Figure 7. Calculation of dune erosion and overwash, 58th Street.

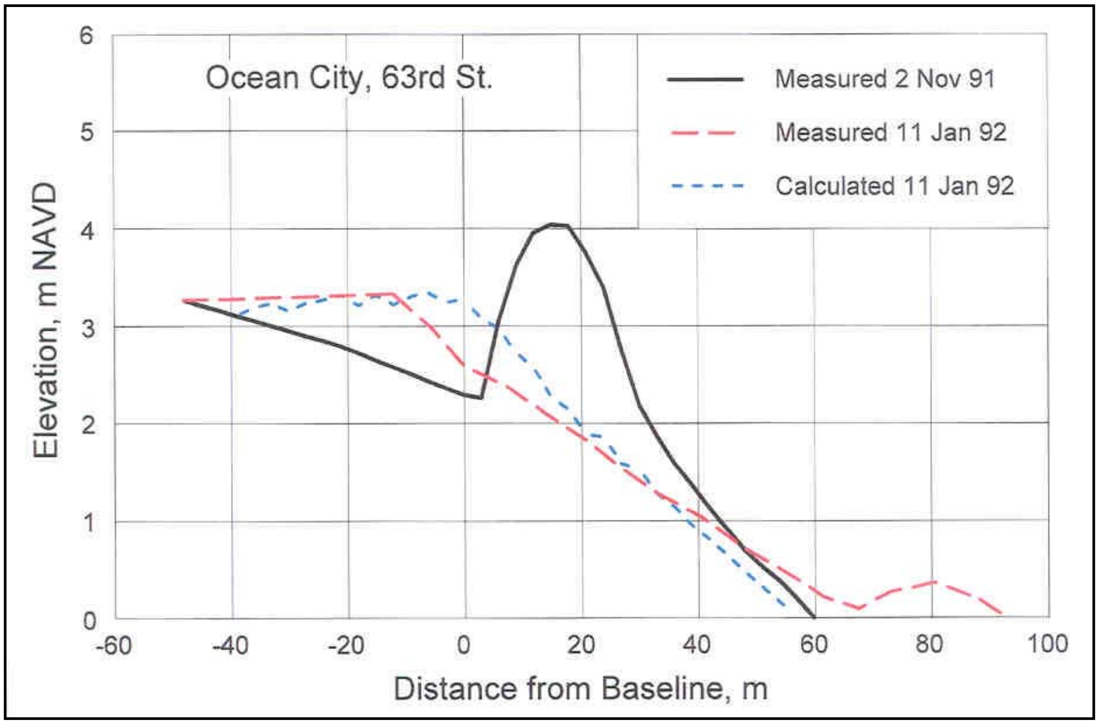


Figure 8. Calculation of dune erosion and overwash, 63rd Street.

The difference in extent of overwash is attributed to dissimilar profile elevations landward of the dune, where lower elevations allow more overwash. The model successfully accounts for these variations in profile response.

At 56th Street (Figure 7), the observed dune response is markedly different from the adjacent profiles. The wider dune base and higher back elevation protected against significant dune lowering and overwash, and this result is reproduced accordingly by the model.

**Overwash of Barrier Island, Northern Assateague Island, MD.** Barrier island overwash is simulated for erosional storms that occurred in January and February 1998 (Figure 9). The 2-month period included two major storms (28 January – 1.6-m peak water level and 4-m peak wave height; and 4 February – 1.7-m peak water level and 4-m peak wave height) and several smaller storm events. All erosional wave conditions within the entire 2-month period were included in the simulations to model cumulative response of the barrier island. Pre-storm beach profiles were surveyed in September 1997, and post-storm measurements were taken in April 1998. Some profile recovery likely occurred during the interval between storms and post-storm surveys, particularly on the seaward face of the barrier island. However, it is reasonable to expect that action of storm surge and overwash on the crest of the barrier island would remain relatively unchanged over the month following the storms.

Figures 10–12 show measured and modeled profile response for three transects (denoted GPS 1, GPS 3, and GPS 4), measured at the north end of Assateague Island near the area most vulnerable to breaching. The pre-storm condition at GPS 1 is a broad low berm approximately 160 m wide with crest at 2 m NAVD backed by a 30-m-wide dune with crest at 3.5 m NAVD. GPS 3 and GPS 4 are both low barrier island sections cresting at 2 m NAVD with no backing dune.

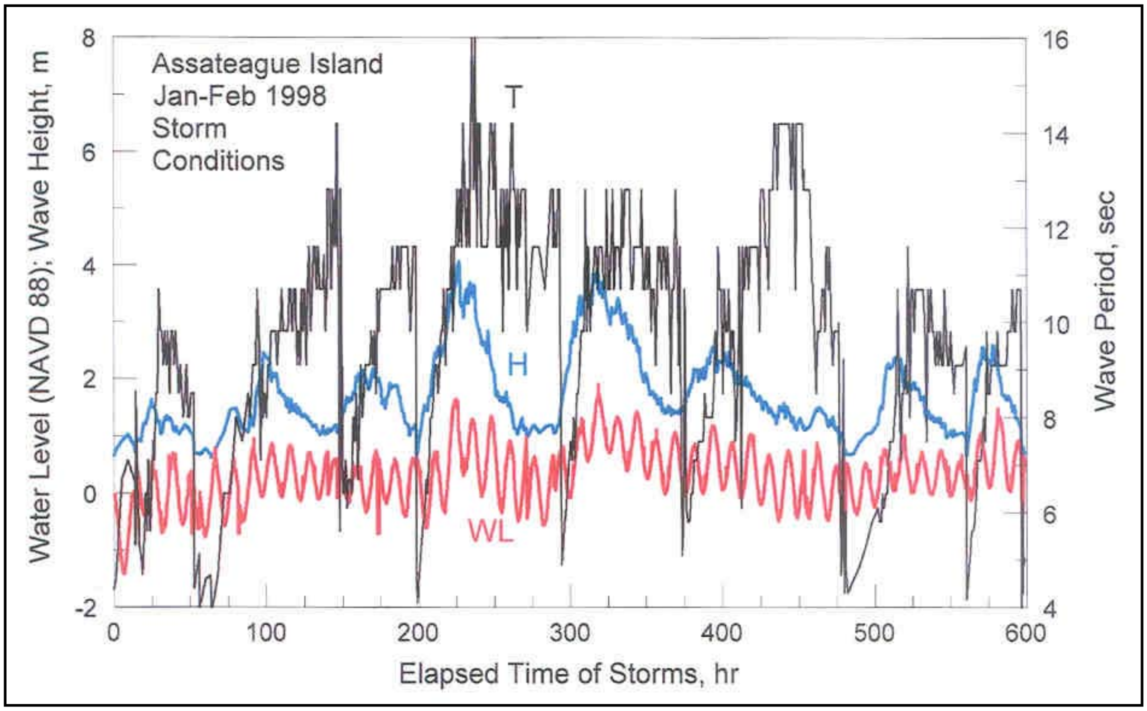


Figure 9. Wave height H, wave period T, and water level WL, for erosional storms occurring January-February 1998 at Assateague Island, MD.

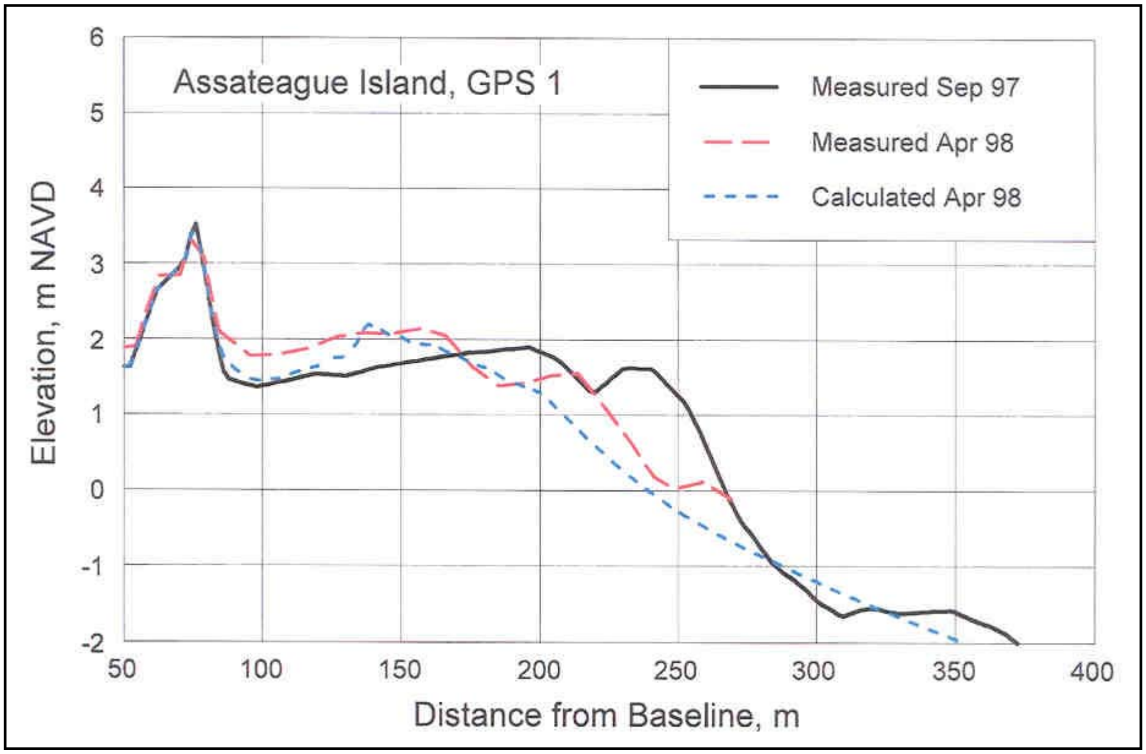


Figure 10. Calculation of barrier island overwash, GPS 1.

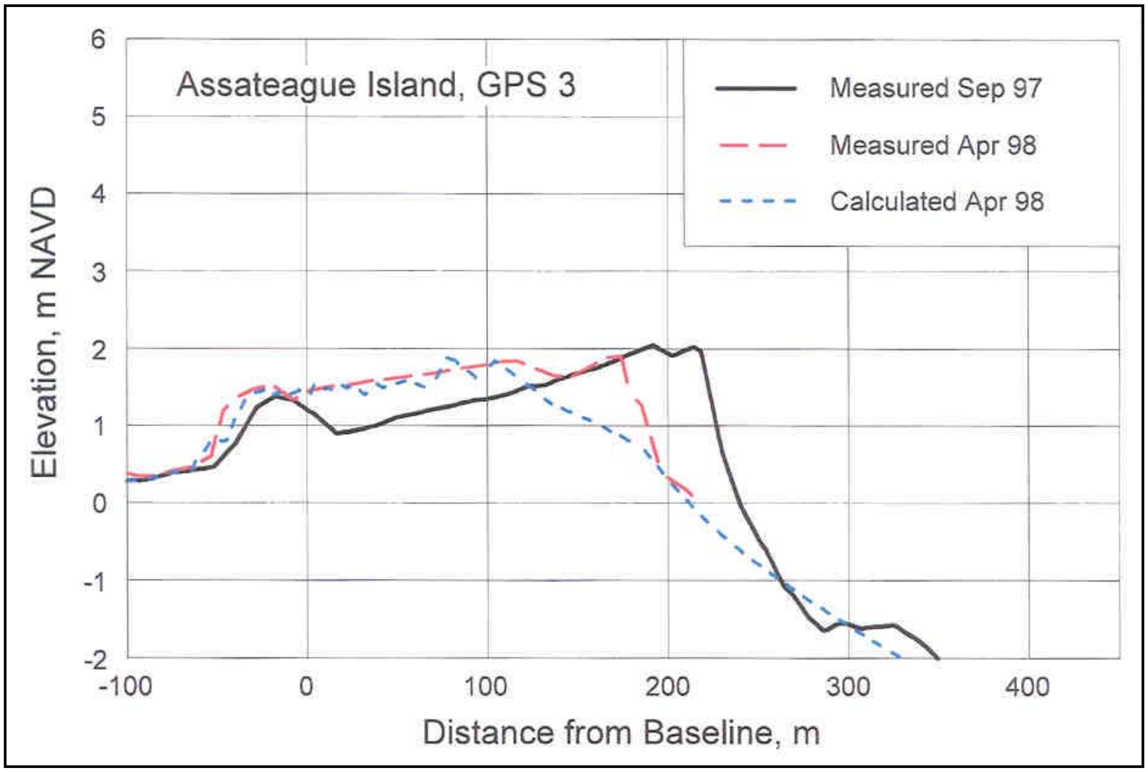


Figure 11. Calculation of barrier island overwash, GPS 3.

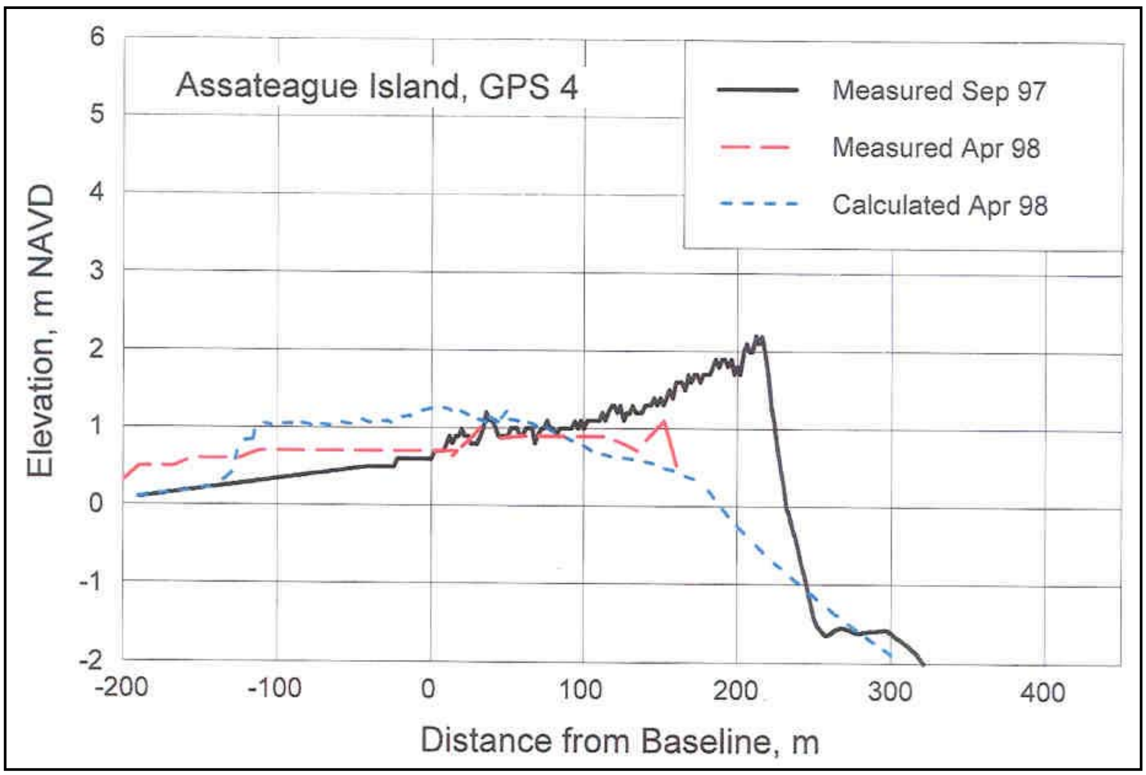


Figure 12. Calculation of barrier island overwash, GPS 4.

**Discussion of Simulations.** At GPS 1, the model accurately simulated horizontal erosion of the berm crest and landward deposition of sand to an elevation higher than the pre-storm crest elevation. The low berm crest at ~1.5 m NAVD observed on the April 1998 profile is likely a poststorm recovery berm that formed subsequent to the modeled period of erosion. The higher berm crest (at approximately 2 m NAVD) was likely produced during the time of higher storm surge and probably better represents the position of the eroded foreshore beach face immediately following the storms. Both the measured and modeled responses show washover extending approximately 160 m landward of the pre-storm berm crest up to the base of the dune. The measurements exhibit a higher volume of washover than indicated by the model, but landward extent of deposition and maximum elevation of deposition are well simulated.

At AI transects GPS 3 and GPS 4, the storms produced significant erosion of the berm crest and large volumes of washover extending from the center to the bay side of the barrier island. For transect GPS 3, the model reproduced recession of the lower beach face, while somewhat overestimating erosion at the berm crest. The volume, extent, and shape of washover is predicted accurately by the model. For transect GPS 4, there is good agreement between simulated and measured erosion of the berm crest. Volume of washover calculated by the model is comparable to measurements, but the horizontal extent and depth of deposition are slightly different. In comparison to the OC data where the horizontal extent of overwash is on the order of tens of meters, the extent of overwash for the AI data is on the order of hundreds of meters. Accuracy of the overwash calculation is considered excellent for a wide variation in modeled conditions, indicating reliability of the model for this range of beach, dune, and storm conditions.

Differences observed between measured and simulated response can be attributed in great part to the inherently three-dimensional (3-D) characteristics of barrier island overwash. Washover fans are typically concentrated at discrete sections along the shoreline, and areas of large washover volume may exist directly adjacent to areas with virtually no washover. The 3-D nature of overwash was evidenced in video taken at Assateague Island by US National Park Service personnel during and after the modeled storms. Employing a two-dimensional (2-D) cross-shore approach precludes representing every detail of overwash along a nonuniform barrier island. Despite the complexity of overwash processes, however, the model performs well in reproducing characteristics of overwash in both the AI barrier island cases and the OC dune cases. Results of the validation indicate the present algorithm provides reliable predictions with no bias toward over-or under-estimation of overwash.

## SAMPLE SIMULATIONS.

SBEACH is applied to five hypothetical barrier island conditions to examine different overwash behavior. The first four simulations model overwash of a 100-m wide barrier island each with different crest elevation (4.5, 2.5, 2.0, and 1.5 m). The fifth simulation calculates overwash for a 200-m-wide barrier island with crest elevation of 2.0 m. The Ocean City November 1991 and January 1992 storms are modeled to provide realistic forcing conditions. Calibration parameters were held at values employed in the model validation.

Figures 13–17 display the simulation results. The sample simulations illustrate different types of predicted response as a function of amount of overwash. The high (4.5-m) barrier island in Figure 13 experiences minimal overtopping, and the model builds a small ridge at the seaward edge of the island as washover sand is deposited at the limit of runup. Orford et al. (2003) observed this behavior at the crest if the runup slightly exceeds the crest elevation.

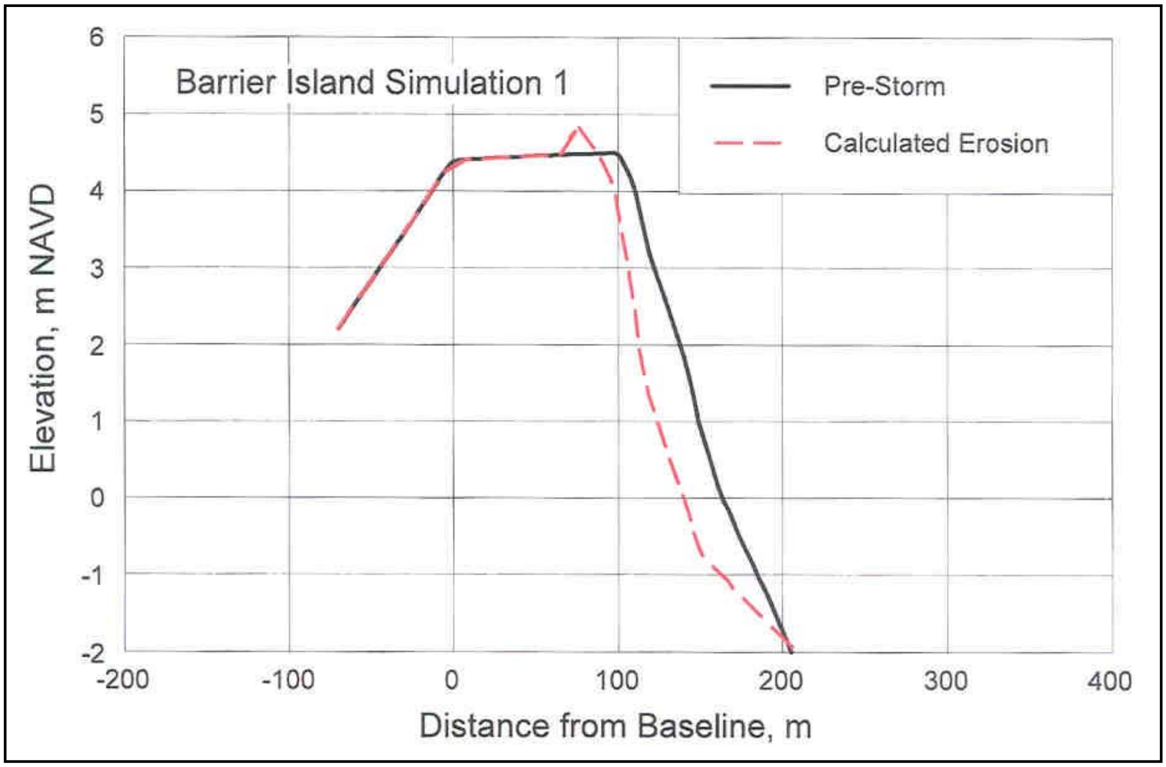


Figure 13. Calculation of barrier island overwash, 100-m crest width at elevation 4.5 m.

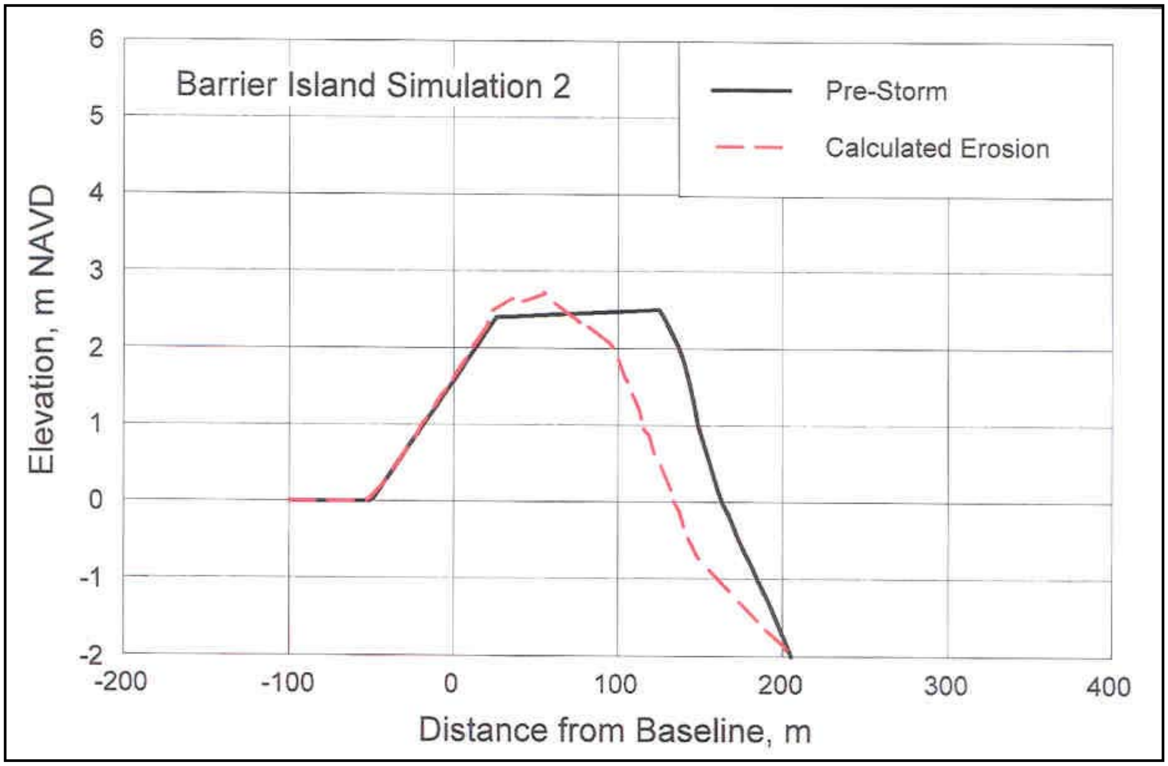


Figure 14. Calculation of barrier island overwash, 100-m crest width at elevation 2.5 m.

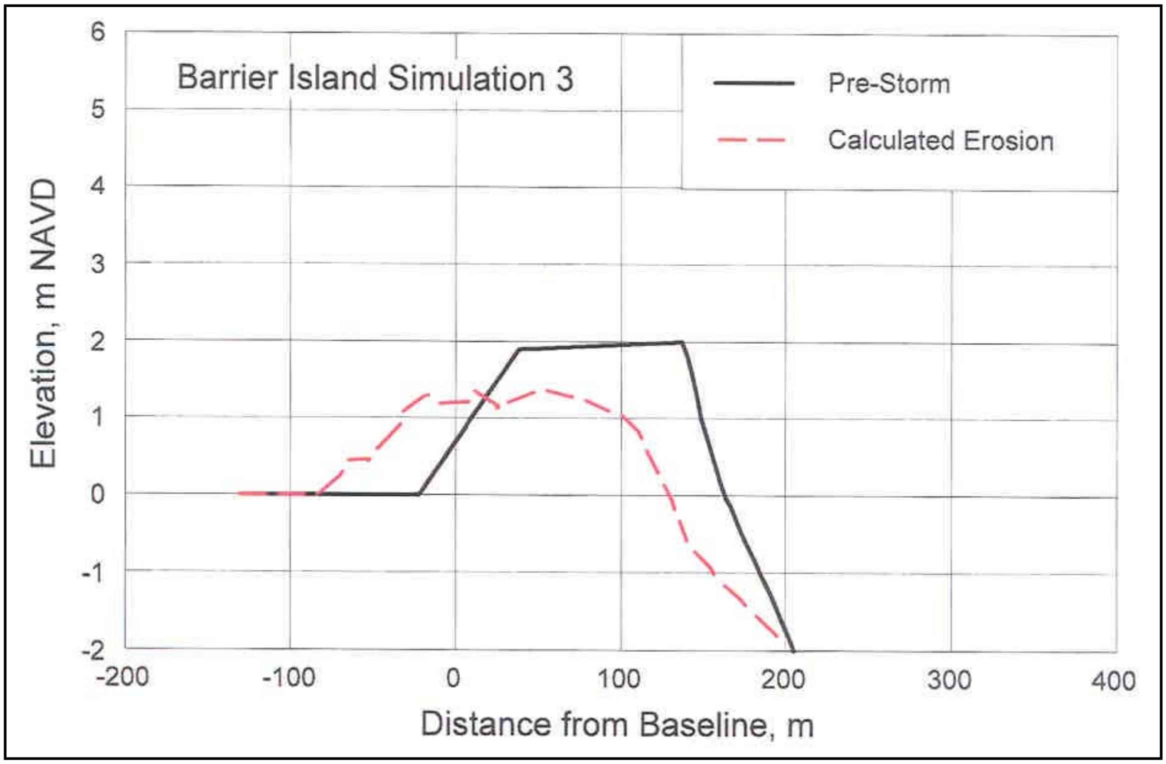


Figure 15. Calculation of barrier island overwash, 100-m crest width at elevation 2.0 m.

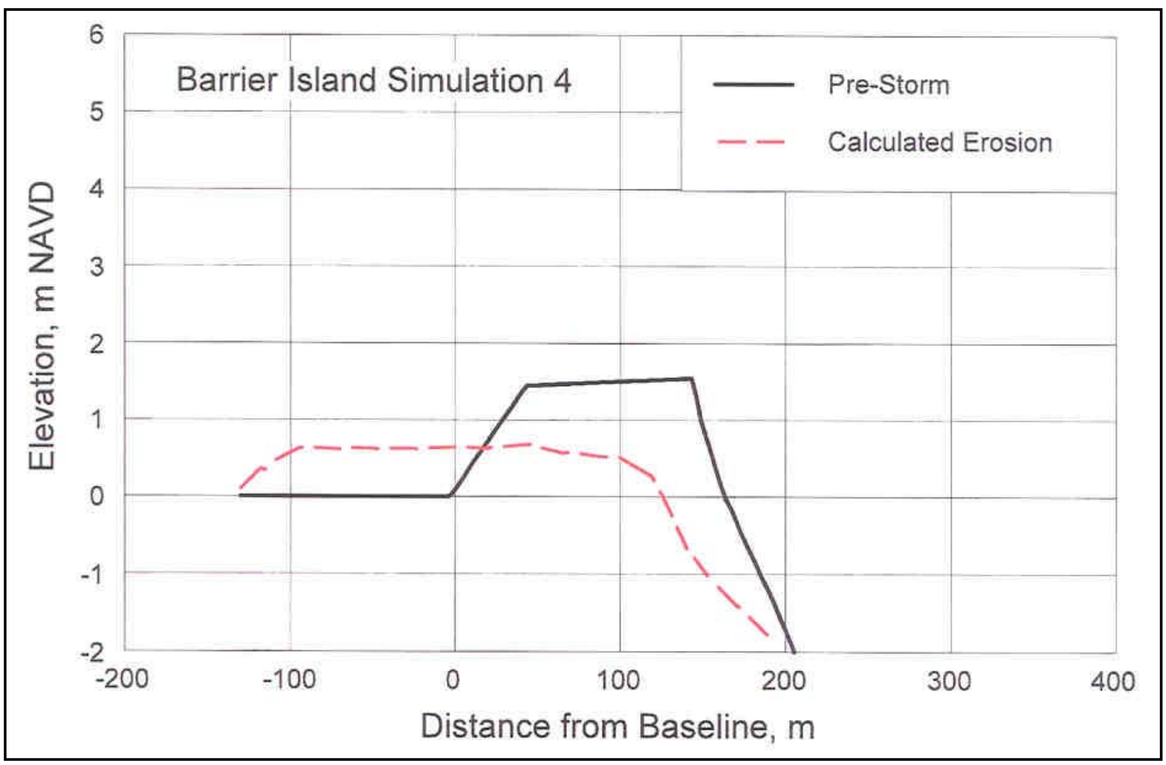


Figure 16. Calculation of barrier island overwash, 100-m crest width at elevation 1.5 m.

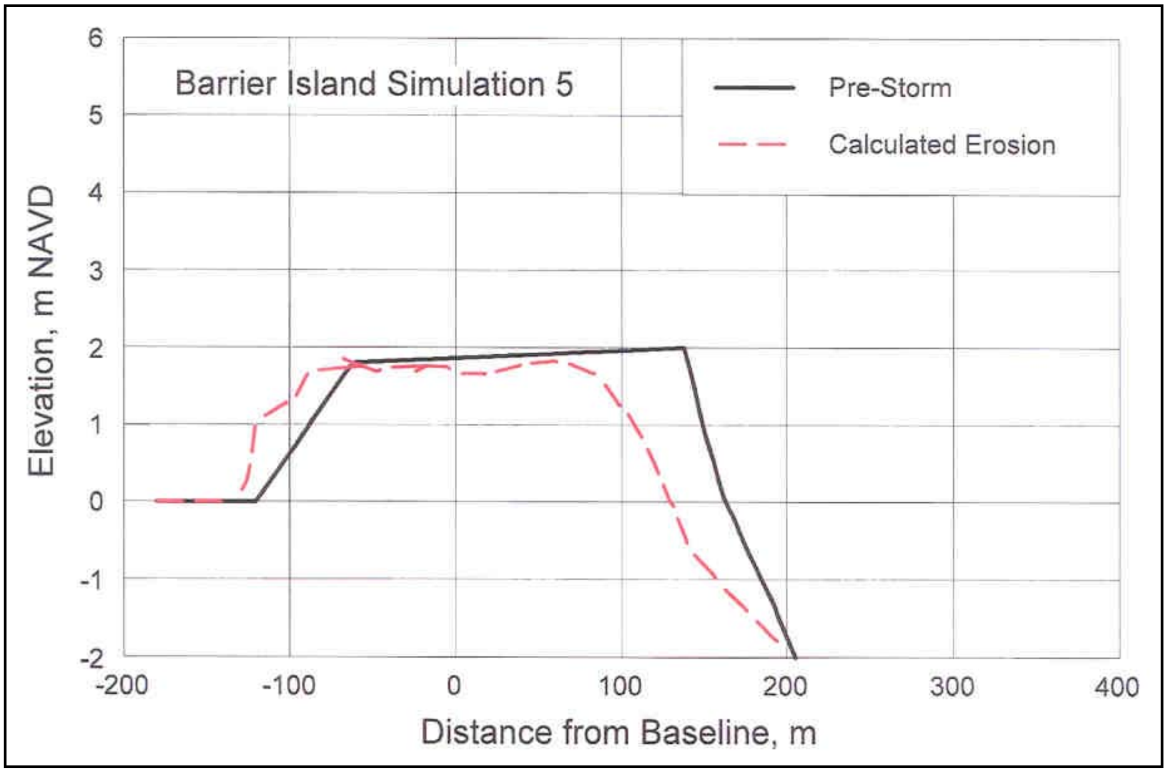


Figure 17. Calculation of barrier island overwash, 200-m crest width at elevation 2.0 m.

Figure 14 indicates that overwash on the 2.5-m-high barrier island extends to the bayward side of the island as runup and overtopping progress further inland because of the lower crest elevation. In Figure 15, the 2.0-m-high island experiences significant crest lowering and deposition of washover sand on the bay side of the island. This response is similar to barrier island “rollover” that is observed during overtopping storm conditions.

Figure 16 displays response of the low 1.5-m-high island, for which SBEACH predicts extensive flattening of the island. This condition produces complete inundation of the island during the storm, and at some point tidal current flow between the bay and ocean would become dominant and lead to breach formation if storm conditions persisted or reoccurred. Although no breaching mechanism presently exists in the model, this situation provides an indication of the conditions and responses that potentially initiate a breach, which can have numerous serious consequences for the environment and society (Kraus 2003, Kraus and Wamsley 2003).

Figure 17 displays overwash calculation for a 200-m-wide and 2-m-high island. In comparison to Figure 15, the wider island experiences less lowering and less deposition of washover on the bay side. These results indicate that both width and height are key characteristics in determining barrier island response to overwash.

CONCLUSIONS. Overwash and associated washover are significant coastal processes that enter both on project scale for individual storms and on the long temporal and wide spatial scales considered in regional sediment management. Overwash can alter the location of the shoreline and volume of the beach. In the absence of shore protection measures, overwash is expected to

increase in amount and location because of relative sea level rise and reduction of sand supply to the coast. Overwash is a precursor to breaching, which can have catastrophic consequences for the environment and society (Kraus and Wamsley 2003). Predictive technology is needed for assessing vulnerability for overwash and to design protective beaches and dunes.

The overwash algorithm in the SBEACH model of storm-induced beach and dune erosion was improved by incorporation of more advanced hydrodynamics and sediment transport considerations. The model was validated at Ocean City, MD, and at Assateague Island, MD, the former representing a location with a protective dune typical of shore protection projects and the latter location representing a low and wide barrier island in a natural condition. The model performed well over the wide range of conditions examined.

Simulations were performed for hypothetical barrier island configurations with different elevations and volumes to demonstrate relative response of the islands to a severe storm. Such simulations indicate how the new technology can both assess beach or island vulnerability to overwash and incipient breaching, as well as design protective beach-fill measures.

ADDITIONAL INFORMATION. This Coastal and Hydraulics Engineering Technical Note (CHETN) was prepared by Dr. Magnus Larson, Professor, Department of Water Resources Engineering, University of Lund, Sweden; Randall A. Wise, Coastal Engineer, US Army Corps of Engineers Philadelphia District; and Dr. Nicholas C. Kraus, Senior Scientist, Coastal and Hydraulics Laboratory (CHL), US Army Engineer Research and Development Center, Vicksburg, MS. The study was conducted as a joint activity of the Coastal Morphology Modeling and Management work unit of the Regional Sediment Management (RSM) program, and the National Shoreline Erosion Control Development and Demonstration Program (Section 227) project at Jefferson County, TX. The assistance by Gregory Bass, US Army Corps of Engineers Baltimore District, and Carl Zimmerman, National Park Service, in obtaining data for Ocean City and Assateague Island; and Ty Wamsley (CHL) and William Grosskopf, Ocean and Coastal Technologies, Inc., Avondale, PA, for technical reviews is acknowledged with appreciation. In addition, Gregory Bass and Carl Zimmerman shared their observations and ideas about overwash and washover processes. Additional information is available at the RSM web site http://rsm.usace.army.mil

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http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-xiv-14.pdf

## REFERENCES.

Cross, R. H. 1967. Tsunami surge force. *Journal of Waterways and Harbors Division*. New York, NY: American Society of Civil Engineers. 93(4):201-231.

Donnelly, C., N. C. Kraus, and M. Larson. 2004. Coastal overwash: Part 1, Overview of processes. Coastal and Hydraulics Engineering Technical Note ERDC/CHL CHETN-XIV-13. Vicksburg, MS: US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-xiv-13.pdf

Hancock, M. W. and N. Kobayashi. 1994. Wave overtopping and sediment transport over dunes. *Proceedings, 24th Coastal Engineering Conference*. Kobe, Japan: American Society of Civil Engineers. pp 2,028-2,042.

Holland, T. K., R. A. Holman, and A. H. Sallenger. 1991. Estimation of overwash bore velocities using video techniques. *Proceedings, Coastal Sediments '91*. Seattle, WA: American Society of Civil Engineers. pp 489-497.

Hughes, M. G. 1992. Application of a non-linear shallow water theory to swash following bore collapse on a sandy beach. *Journal of Coastal Research.* 8(3):562-578.

Kraus, N. C. 2003. Analytical model of incipient breaching of coastal barriers. *Coastal Engineering Journal.* 45(4):511-531.

Kraus, N. C. and R. A. Wise. 1993. Simulation of January 4, 1992 storm erosion at Ocean City, Maryland. *Shore and Beach.* 61(1):34-41.

Kraus, N. C. and T. V. Wamsley. 2003. Coastal barrier breaching; Part 1, Overview of breaching processes. Coastal and Hydraulics Engineering Technical Note ERDC/CHL CHETN-IV-56. Vicksburg, MS: US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory.
http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-iv-56.pdf

Kobayashi, N., Y. Tega, and M. W. Hancock. 1996. Wave reflection and overwash of dunes. *Journal of Waterways, Port, Coastal, and Ocean Engineering.* New York, NY: American Society of Civil Engineers. 122(3):150-153.

Larson, M. and N. C. Kraus. 1989. SBEACH: Numerical model for simulating storm-induced beach change; Report 1, Empirical foundation and model development. Technical Report CERC-89-9. Vicksburg, MS: US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. http://acwc.sdp.sirsi.net/client/search/asset/1001038

Larson, M., and N. C Kraus. 1998. SBEACH: Numerical model for simulating storm-induced beach change; Report 5, Representation of nonerodible (hard) bottoms. Technical Report CERC-89-9. Vicksburg, MS: US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. http://acwc.sdp.sirsi.net/client/search/asset/1001040

Larson, M., N. C Kraus, and M. R. Byrnes. 1990. SBEACH: Numerical model for simulating storminduced beach change; Report 2, Numerical formulation and model tests. Technical Report CERC-89-9. Vicksburg, MS: US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center. http://acwc.sdp.sirsi.net/client/search/asset/1001039

Larson, M., S. Kubota, and L. Erikson. 2001. Modeling sediment transport and profile evolution in the swash zone. *Proceedings, Coastal Dynamics '01*. Lund, Sweden: American Society of Civil Engineers. pp 908-917.

Larson, M., S. Kubota, and K, Erikson. 2004a. Swash-zone sediment transport and foreshore evolution: Field experiments and mathematical modeling. *Marine Geology.* 212(14):61-79.

Larson, M., R. A. Wise, and N. C. Kraus. 2004b. Modeling dune response due to overwash transport. *Proceedings, 29th Coastal Engineering Conference*. Lisbon, Portugal: American Society of Civil Engineers.

Miller, R. L. 1968. Experimental determination of run-up of undular and fully developed bores. *Journal of Geophysical Research.* 73(14):4,497-4,510.

Orford, J., S. Jennings, and J. Pethick. 2003. Extreme storm effect on gravel dominated barriers. *Proceedings, Coastal Sediments '03*. Clearwater, FL: American Society of Civil Engineers. Also CD ISBN-981-238-422-7. World Scientific Press and East Meets West Productions, Corpus Christi, TX.

Schüttrumpf, H. 2003. Wave overtopping flow on seadikes. Experimental and theoretical investigations. *PIANC Bulletin 114*. Amsterdam, The Netherlands: Permanent International Association of Navigation Congresses.

Shen, M. C., and R. E. Meyer. 1963. Climb of a bore on a beach; Part 3, Run-up. *Journal of Fluid Mechanics.* 16:113-125.

Waddell, E. 1973. A field investigation of swash characteristics. *Coastal Engineering in Japan.* 16:61-71.

Wise, R. A., S. J. Smith., and M. Larson. 1996. SBEACH: Numerical model for simulating storm-induced beach change; Report 4, Cross-shore transport under random waves and model validation with SUPERTANK and field data. Technical Report CERC-89-9. Vicksburg, MS: US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center.
http://chl.erdc.usace.army.mil/Media/4/2/8/CERC_89-9%20report%204.pdf